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Environmental performance of cocoa production from monoculture and agroforestry systems in Indonesia

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ABSTRACT

Indonesia is seeking to expand its cocoa production to meet the increased international demand. However, this effort faces economies of scale and ecological challenges. This research aims at evaluating environmental performance of cocoa production from cocoa monoculture and cocoa-agroforestry by life cycle assessment based on ISO 14040 and 14044, with adaptation for local impact indicators. This study defined cocoa-agroforestry as raw and sequential of cocoa–coconut and cocoa–rubber agroforestry, combined with shading trees *Leucaena* sp. and *Gliricidia sepium*. The analysis considered cocoa production at farm level, from cradle to on-farm gate boundary for 1 metric tonne of cocoa pod. The results showed that cocoa–coconut agroforestry had the least contribution to global impact categories of global warming, acidification and eutrophication, accounting for 3.67E+01 $kgCO_2$-eq, 4.31E-02 $kgSO_2$-eq, and 2.25E-05 $kgPO_4$-eq respectively. Cocoa–coconut agroforestry also had the highest organic carbon and soil organic matter, conditions supporting the growth and activity of beneficial soil microbeds (*Pseudomonas* sp. and *Trichoderma* sp.). In addition, total land equivalent ratio of cocoa–coconut agroforestry had the highest value at 1.36, indicating a highest yield advantage was gained. Therefore, cocoa–coconut agroforestry could be a wise option to promote environmental sustainability of cocoa cultivation.

1. Introduction

Cocoa plays an important role in the life of 40–50 million people who depend on cocoa for their livelihood (Cocoa Market Update, 2012). During 2006–2011 the average Indonesia's cocoa beans production reached 779,899 metric tons, placing Indonesia as the second largest producer of cocoa in the world (FAO Statistics, 2013), and contributing to national export income of about USD 874 million (Ministry of Trade, 2012).

As there are no alternative crops or synthetic products to make chocolate, cocoa production is expected to increase to meet market demand. Despite the increased demand, Indonesia's cocoa production faces challenges. The cocoa yield ratio in some regions has tended to decline in recent years. Due to current low productivity, cocoa cultivation is commonly expanded into new areas including forest lands or intensified by fertilizer application to increase yield putting undue pressure on the environment. To cope with these challenges, Indonesia launched National Movements on Revitalized Cocoa in 2008 that follows the principle of sustainability and recommends the application of polyculture as combined plantation of cocoa and other valued species to obtain better economic, social and environmental advantages (Neilson, 2008).

Environmental sustainability in cocoa cultivation may encompass conservation of soil, forest and water resources, and biodiversity protection (ICCO, 2007). Since cocoa trees naturally need shade, reintroduction of shade trees is currently being focused on to reverse the trend of intensified cocoa plantations because the intensified agriculture practices contribute negative impacts to the environment. Agricultural production is usually a hotspot in the life cycle of food products (Poritosh et al., 2009), the farm stage being a major contributor to the impact categories of global warming, eutrophication and toxicity (Salomone, 2003; Pleanjai and Gheewala, 2009; Humbert et al., 2009; Cappelletti et al.,

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2010). The hotspots of emissions contributing to the three mentioned impacts are the production and use of fertilizers, notably for global warming and eutrophication, and the use of pesticide and fertilizers for toxicity impacts (Ntiamoah and Afrane, 2008).

Given the increased public attention to the areas of protection, the need to assess the environmental impact of agriculture has also been spreading out to a large number of agricultural commodities, including cocoa. This research aims at evaluating environmental performance of cocoa production from cocoa monoculture and cocoa-agroforestry systems in order to promote sustainable agricultural practices in cocoa cultivation.

2. Material and methods

2.1. Cocoa cultivation practices in the study area

This research was carried out in 5 rain-fed cocoa farms belonging to national plantation company in Banyuwangi Regency, Indonesia. The farms were purposively selected, with Criollo cultivar, consisting of 1 plot of cocoa monoculture at Kali Kempit district, 2 plots of cocoa–coconut agroforestry at Kali Kempit and Kali Rejo district, and 2 plots of cocoa–rubber agroforestry at Kali Rejo and Kali Kempit district. Cocoa monoculture is defined as full-sun-grown cocoa intercropped with *Leucaena* sp. and *Gliricidia sepium*, which was previously a shifting cultivation farm. Meanwhile, cocoa–coconut and cocoa–rubber agroforestry are simple agroforestry systems with shade-grown cocoa intercropped beneath planted coconut trees and a well-developed secondary rubber forest canopy respectively (Fig. 1).

Plot-1 of cocoa monoculture applied 3 m × 3 m planting space for cocoa, while shading trees (*Leucaena* sp. and *G. sepium*) were planted in horizontal lines with the same space. To ensure adequate plant stand in the cocoa monoculture, a higher seed rate was used at sowing and excess plants were a later removed to maintain the required cocoa plant population. Cocoa seeds were planted in the rainy season. At the first stage, the estimated number of seeds to be planted by the company was 1265 stands with 4–6-month old seedlings or grafted or budded plants. Plot-1 of cocoa monoculture was established at high planting density; with 1100 cocoa trees, excluding the existence of shading trees. As commercial cocoa stands, 3.0 m × 3.0 m spacing with density of 1100–1200 cocoa trees ha^{-1} is commonly established in Indonesia. This is considered as conventional cocoa planting model in order to maximize cocoa yield. Fig. 2 provides an illustrative planting model for cocoa monoculture, which is expected to provide 1 shading tree for 4 cocoa trees.

Cocoa can be grown in multi-strata and diversified agroforestry systems where the canopies of cocoa tree are joined up and form a thick layer of foliage shaded by the canopy of neighbor trees (Wessel, 1985). As a tree crop, cocoa is highly suitable with different production systems, such as agroforestry. The existence of trees with crops is defined as an agroforestry system (Malézieux et al., 2009). Cocoa agroforestry in the study area is planted in sequence or rows whose main crops such as coconut (*Cocos nucifera*) and rubber (*Hevea braziliensis*) are planted in between cocoa trees and other shading trees. Such practice has been developed by the company as commercial plantation by transplanting unproductive cocoa tree with commercial trees, or cultivating cocoa–rubber agroforestry at the beginning stage. Instead of having cocoa pod production, cocoa-agroforestry cultivation aims at diversifying products (co-products of coconut sap and raw latex) and minimizing agrochemicals use.

Plot-2 of cocoa–coconut agroforestry applied 3 m × 3 m space for both cocoa and shade tree, and spacing 9 m × 12 m for coconut. Plot-3 applied 3 m × 4 m planting space for both cocoa and shade tree, and 15 m × 18 m for coconut. Coconut trees were firstly planted at the 1st - 2nd year, then shading trees at the 3rd -4th year. Coconut trees and shading trees were cultivated in horizontal lines. The latest planting schedule in the 5th year was cocoa. Plot-4 of cocoa rubber agroforestry applied 3 m × 3 m spacing for both cocoa and shade tree planting. Rubber tree has a planting space of 3 m × 4 m, cultivated into separate blocks, consisting only two rows of rubber trees row in vertical line. Distance between cocoa block and rubber block is 4.5 m whilst, plot-5 applied 4 m × 3 m space for both cocoa and shade tree, and 3 m × 4 m for rubber. Distance between block of cocoa and rubber is 5 m. Planting schedule of rubber and shading trees was at the 1st–2nd year and cocoa trees at the 3rd–4th year.

2.2. Methodology

2.2.1. Boundary of the system

The application of cradle-to-gate type of Life Cycle Assessment based on ISO 14040 and 14044 (ISO, 2006a,b) was chosen to evaluate the environmental impacts of cocoa pod production at farm level, with two scenarios of cultivation system: cocoa monoculture and cocoa-agroforestry. Cocoa-agroforestry refers to a simply structured system, named as “sequential or row agroforestry” (Malézieux et al., 2009) where the performances and impacts could be quantified for each crop individually, based on corresponding crop performances and impacts assessed in single-crop systems (Bessou et al., 2013).

The life cycle assessment focused on farm level activities, consisting of (1) nursery stage, (2) unproductive stage (immature phase and any decline in production at the end of life), and (3) productive stage, having cycle of cocoa cultivation from the establishment of farm, farm maintenance, crop protection, harvesting and packing. The functional unit used was 1 metric tonne of cocoa pod.

Fig. 1. Cocoa cultivation practices in the study area; (a). Monoculture, (b). Cocoa–coconut agroforestry and (c). Cocoa–rubber agroforestry (*Picture: B. Utomo*).